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Minimal Walking Technicolor Spectroscopy

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Supervisor: Luigi Del Debbio Work with: LdD, Biagio Lucini, Francis Bursa, et. al

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Standard Model

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$\mathcal{L}_{SM} = \mathcal{L}_{G} + \mathcal{L}_{F} + \mathcal{L}_{H}$

$$\mathcal{G}_{SM} = SU(3)_C \times SU(2)_I \times U(1)_Y$$

$$\downarrow$$
 $\mathcal{G}_{obs} = SU(3)_C \times U(1)_{EM}$

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SM minus Higgs

$$\mathcal{L} = \mathcal{L}_{G} + \mathcal{L}_{F}$$

$$\mathcal{G} = SU(3)_{\mathcal{C}} \times SU(2)_{\mathcal{I}} \times U(1)_{\mathcal{Y}}$$

$${\cal L}_{\cal C} + {\cal L}_q
ightarrow {\cal L}_\chi = rac{f^2}{4} {
m Tr}[(D^\mu \Sigma)^\dagger D_\mu \Sigma]$$

$$D_{\mu}\Sigma = \partial_{\mu}\Sigma - i\frac{g}{2}\tau^{a}A_{\mu}^{a}\Sigma + i\frac{g'}{2}\Sigma\tau^{3}B_{\mu}$$

$$\Sigma = \exp\left(\frac{2i}{f}\tau^a\pi^a\right)$$

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$$\begin{split} |D_{\mu}\Sigma|^{2} &= \frac{g^{2}}{4} \left(A'^{a}_{\mu} - \frac{4}{fg} \partial_{\mu}\pi^{a}\right)^{2} \\ (A')^{a}_{\mu} &= \left(A^{1}_{\mu}, A^{2}_{\mu}, A^{3}_{\mu} - \frac{g'}{g} B_{\mu}\right) \\ W^{a}_{\mu} &\equiv A'^{a}_{\mu} - \frac{4}{fg} \partial_{\mu}\pi^{a} \\ Z_{\mu} &\equiv \frac{g}{\sqrt{g^{2} + g'^{2}}} W^{3}_{\mu} \end{split}$$

 $\mathcal{G} = SU(3)_C \times SU(2)_I \times U(1)_Y \rightarrow SU(3)_C \times U(1)_{EM}$

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$QCD \times 10^3$

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Can we use this mechanism at the GeV scale?

$$\mathcal{G}_{TC} = \mathcal{G}_{SM} \times SU(N_T)$$

- N_D techniquark pairs (U, D)
- Becomes strong at $\Lambda_{\mathcal{TC}}\sim\!\!100~\text{GeV}$

$$\langle \bar{T}_{iL} T_{jR} \rangle \sim \delta_{ij} \Lambda_{TC}^3$$

$$F_T \sim \sqrt{rac{N_T}{3}} \left(rac{\Lambda_{TC}}{\Lambda_{QCD}}
ight) f_\pi$$

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Minimal Walking Extended Technicolor Technicolor Spectroscopy Except! $m_{q,l} = 0$ Eoin Kerrane $\mathcal{G}_{FTC} \supset \mathcal{G}_{TC}$ Extended $F_T^2 M_{\pi_T}^2 \simeq 2m_T (M_{ETC}) \langle \bar{T} T \rangle_{ETC}$ $\alpha: \overline{T}\gamma_{\mu}T$ $m_{q,l}(M_{ETC}) \sim \frac{1}{\Lambda_{ETC}^2} \langle \bar{T}T \rangle_{ETC}$ $\beta: \bar{T}\gamma_{\mu}q$ $2M_K^0 \Delta M_K(M_{ETC}) = \frac{Re(\gamma_{sd}^2)}{2\Lambda_{ETC}} f_k^2 M_K^2$ $\gamma: \bar{q}\gamma_{\mu}q$ $S \simeq N_D \frac{d(R)}{\epsilon}$ ・ロト ・ 理 ト ・ ヨ ト ・ ヨ ト

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Condensate

• Masses from ETC depend on

$$\langle \bar{T} T \rangle_{ETC} = \langle \bar{T} T \rangle_{TC} Z(\Lambda_{TC}, \Lambda_{ETC})$$

 $Z(\Lambda_{TC}, \Lambda_{ETC}) = \exp\left(\int_{\Lambda_{TC}}^{\Lambda_{ETC}} \frac{d\mu}{\mu} \gamma(\mu)\right)$

- Before assumed $\gamma(\mu) \sim \alpha_{TC}(\mu) \rightarrow 0$ for $\mu > \Lambda_{TC}$ and so $Z \sim 1$
- If γ constant between Λ_{TC} , Λ_{ETC} then

$$Z \sim \left(\frac{\Lambda_{ETC}}{\Lambda_{TC}}\right)^{\gamma} \tag{1}$$

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What walks?

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$$\beta(g) = -\beta_0 g^2 - \beta_1 g^3$$

$$\beta_0 = \frac{1}{4\pi} \left(\frac{11}{3} N_c - \frac{4}{3} T(R) N_f \right)$$

$$\beta_1 = \frac{1}{(4\pi)^2} \left[\frac{34}{3} N_c^2 + \left(\frac{1}{N_c} - \frac{13}{3} N_c \right) N_f \right]$$

Three possibilities:

- QCD-like
- Walking
- Conformal

Suggested that conformal theories would also serve to help technicolor in the same way.

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Minimal Walking Technicolor

- $\mathcal{G}_{TC} = SU(2)$, & 2 adjoint fermions
- Attracted considerable theoretical interest
- Gauge coupling unification
- Dark Matter Candidates

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Non-perturbative problem

- Increasingly active field in recent years
- Attention to many different theories N_f , N_c , R.
- Two approaches
 - Running Coupling (SF Method)
 - Spectrum Measurements
- Several studies of MWT. Some evidence for novel behaviour.
- Bulk phase transition $\beta\sim 2$

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Framework

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- Complements previous work
- Wilson fermions, $\beta = 2.25$
- Configs from HiRep code
- Smeared Inversion using modified Chroma
- Observables: $am_{PCAC} = am$, $am_{PS} am_V$, $a^2 G_{PS}$, af_{PS} , af_V

Meson Masses

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Decay Constants

Pseudoscalar Decay Constant



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Ratios

Ratio of m_V to m_PS

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Anomalous Dimension Fits

 $M_{\rm X} \sim m^{rac{1}{1+\gamma}}$

- In a conformal scenario all observables of mass dimension one are expected to scale together (hyperscaling).
- Initial fits of masses to universal curves suggest $\gamma \leq$ 0.5

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Fitting Anomalous Dimensions



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Summary

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- MWT is an interesting Yang-Mills theory could help Technicolor avoid EW & Flavour constraints.
- Indications of novel near-conformal dynamics
- Preliminary simulations must be extended in order to gain additional precision.

Future Work

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- Complete scaling analysis
- Evaluate MWT contribution to S